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EVALUATION OF MECHANICAL CHARACTERISTICS OF HYBRID AA7068/TIB_2/FA METAL MATRIX COMPOSITE

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ABSTRACT

In automobile industries, hybrid metal matrix composite plays a key role, as it executes high tribological characteristics, mechanical properties and low density with high vibration damping capability. In this article, the hybrid composite material is fabricated through stir casting technique. The mechanical characteristics are experimentally investigated in the view of the automobile industry. AA7068 has selected for the matrix material, as it has the highest strength among the aluminium alloy family, while it is heat-treated to a specific treatment. TiB_2 and fly ash are adopted as reinforcement material with varying weight percentages in the matrix. TiB_2 particle is a primary reinforcement, which belongs to the ceramics family and fly ash is a secondary reinforcement, which is readily available as industrial waste. It is observed that mechanical characteristics of the hybrid composite are varied with the weight percentage of reinforcement. The hardness, tensile and compressive strength are improved by 50.22%, 94.5% and 6% respectively, while incubated with 1 wt.% TiB_2 and 2 wt.% fly ash.

KEYWORDS: AA7068, TiB2; Fly Ash, Stir Casting, Tribological & Mechanical Characteristics

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Original Article

INTRODUCTION

The continuous demands of customers are the moving targets for the automotive industries and researchers. When the industries and researchers are about to fulfil the needs, the next set of demands and requirements are already set. Its parameters for further research and target. This type of catch condition pushes the automobile industries and researchers to develop the materials and specify its application in advance stages. The increased demand for high strength with lightweight material in automobile and aerospace industries has led to the aluminium alloy-based MMCs. The market is dominated by alloy metals, which are gradually being substituted by MMCs, where the lightweight, energy-saving and strength are the areas of interest. A different set of characteristics, i.e., mechanical, electrical, physical and electrical can be achieved by incubating different types of reinforcements [1]. Such an improved set of properties can be achieved by MMCs only, while alloys execute specific properties, which are limited to the heat treatment processes. The promising characteristics of particle-reinforced MMCs are an attractive substitute for structural and engineering application [2]. MMCs execute promising wear resistance, low thermal expansion and high mechanical properties by introducing ceramic particulates in the metal matrix. The ceramic particle ZrO_2, B_4C, TiC, Al_2O_3 and SiC enhance the thermal shocks and harness the MMCs, while utilized as a reinforcement phase in the metal matrix [3, 4]. Some other reinforcements, such as AlB_2[5], CeO_2[6], granite[7], glass[8], Ni_3Al[9], TiO_2[10] and AIN[11] are the effective reinforcement particles to enhance tribological properties of aluminium alloy-based composite material. Due to the high strength and hardness of the reinforcement particles,

the wear resistance improves, as the percentage increases. For the development of hybrid MMCs, primary reinforcements are generally from the ceramic family, as it executes superior strength among other reinforcements, while the secondary reinforcement is incubated to lower the cost of hybrid composites, as they have lower density and are readily available, as wastes of industries or as by-products [12, 13]. New-fangled research has revealed that fly ash, rice husk, graphite, etc., which are industrial/agro-waste, can be utilized as reinforcement in composite [14–17]. Incubation of hybrid reinforcement not only increases the composite performance but also includes new features. Such inclusion reduces the cost of aluminium composite [14,15]. Low density plays a significant role in controlling the weight of composite [16]. The hybrid metal matrix composite has a significant capability to replace the single reinforcement composite due to improved characteristics. Hybrid metal matrix composite cans state a second-generation composite [18].

AA7068 is a matrix material, known as zinc alloy, as it has a high percentage of zinc element. AA7068 is the strongest alloy in the aluminium alloy family. It is commercially available and can be compared to steel. AA7068s are broadly utilized by ordnance, automobile and aerospace application, such as connecting rods, valve body, prosthetic limbs, bicycle frame and climbing equipment [19].

In the ceramic family, TiB_2 has a very high value of hardness with high resistance to wear. Due to such promising characteristic, it is utilized as reinforcement in aluminium matrix composite. It significantly increases the hardness of composite material. Also, it increases the density of composite material, as it possesses high-specific gravity [20]. Higher tensile strength is observed, while TiB_2 is used as reinforcement as compared to SiC-reinforced composite [21].

Fly ash is post form of mineral matter, which is available in coal. Fly ash is readily available as waste material for the thermal power plants, which increase the attention of researchers and industries to utilize this waste as an additive material for different applications [22]. Fly ash is classified into solid fly ash and cenosphere. Cenosphere consists of hollow spheres and are utilized to fabricate ultra-lightweight composite material due to its low-specific gravity. On the contrary, solid fly ash are utilised to improve wear resistance, reduce density, stiffness and strength of metal matrix [23]. The lightweight automotive components, i.e., the piston and connecting rod are more preferable materials due to market requirement [24].

MATERIAL AND METHODS

Matrix Material

Aluminium alloy 7068 (AA7068) is procured by parshwamani metals, Mumbai, India. The AA7068 is the strongest alloy among the other aluminium alloys. AA7068 is widely utilized for aerospace, automobile, defence application and in the area where strength is a dominating parameter [25]. The chemical and physical properties of the metal matrix are shown in Table 1 and Table 2, respectively.

Table 1: Chemical Composition of Matrix Material

Elements	Zn	Mg	Cu	Fe	Mn	Ti	Si	Cr	Ni	Al
% Ratio	8.3	3.03	2.42	0.192	0.034	0.05	0.142	0.05	0.0075	85.51

Table 2: Physical Properties of Matrix Material

Properties	Density	Melting Point	Modulus of Elasticity	Poisson's Ratio
Values	2.85 g/cc	476-635°C	73.1 GPa	0.23

Reinforcement Material

In the present investigation, Titanium Diboride (TiB_2) and Fly ash (FA) are chosen as reinforcements. For the development of hybrid composite, Titanium Diboride is selected as a primary reinforcement and fly ash is selected as secondary reinforcement.

Titanium Diboride has high wear resistance along with high hardness value. It possesses high strength at elevated temperature. It is known as a ceramic material with high strength and hardness [26]. The particle size of Titanium Diboride (TiB_2) is kept about 10 – 30 μm for the fabrication of composite. Titanium Diboride (TiB_2) is procured by parshwamani metals, Mumbai, India.

Fly ash is a by-product of coal. It is readily available as a waste of thermal power plants. For current experimental investigation, flyash (FA) collection is done from the MPPGCL, Sarni, Madhya Pradesh 460447, India. Physical and mechanical properties of Titanium Diboride (TiB_2) Table 3. The collected fly ash is cleaned and washed with water and dried at room temperature for 15 days followed by sieve process for the segregation of average particle size from 40–75 μm.

Table 3: Physical and Mechanical Properties of Titanium Diboride (TiB_2)[27]

Properties	Values
Density ($g.cm^{-3}$)	4.52
Melting point (^oC)	2970
Modulus of Rupture (MPa)	410–448
Elastic modulus (GPa)	510–575
Poisson's ration	0.1-015
Thermal conductivity (W/mK)	25

Material Fabrication

Stir casting processes is opted to fabricate the AA 7068 containing 1 wt.% TiB2 particulate with an average particle size of 10–30 µm and 2, 3 and 4 wt.% of fly ash with an average particle size of 40-75 µm. The schematic diagram of stir casting setup is shown in Figure 1. The AA7068 were procured in the form of ingots. It is cut down in small pieces for proper accommodation in the graphite crucible. Matrix material melted in a graphite crucible of 3-litre capacity in an electric furnace. The furnace temperature is set at 740oC, which increases gradually. Matrix material starts meltdown at 660oC. Reinforcements are preheated at 400oC for the time of 120 minutes in order to remove the moisture from the particles. Graphite-coated three-blade stirrer is gradually inserted into the molten metal and initiates the stirring to ensure the vortex formation in the molten melt, then after preheated reinforcements are added into the molten metal at 740 oC through vibratory funnel during stirring. Stirring is continuous for 5–7 minutes at 500 rpm to ensure the homogeneous distribution of particles in the melt. A graphite rod is utilized to add magnesium to increase wetting between particle surface and matrix. Dry nitrogen purging is done for three minutes to reduce the porosity in the composite. The reinforced melt was poured into a preheated graphite dye about 500 oC, and left for the solidification at room temperature. Five castings are prepared, including the aluminium alloy, out of which four are hybrid composites and one is monolithic material, i.e., AA7068. Prepared material samples and their acronyms are shown in table 4. Standard specimen for the testing are shown in figure 2.

Figure 1: A Schematic Diagram of Stir Casting Setup.

Table 4: Acronyms and Composition of Hybrid Composite

Sl. No.	Composition	Acronym's
1.	100 wt.% AA7068	S-0
2.	99 wt.% AA7068 - 1 wt.% TiB_2 - 0 wt.% FA	S-1
3.	97 wt.% AA7068 - 1 wt.% TiB_2 - 2 wt.% FA	S-2
4.	96 wt.% AA7068 - 1 wt.% TiB_2 - 3 wt.% FA	S-3
5.	95 wt.% AA7068 - 1 wt.% TiB_2 - 4 wt.% FA	S-4

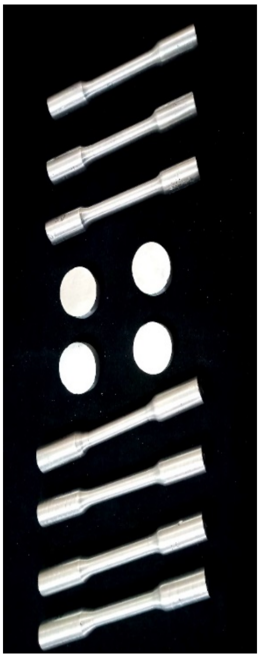

Figure 2: Standard Specimen for Testing.

Density and Porosity Measurement

Density measurement is done by Archimedes' principle on base alloy and hybrid metal matrix composite. The principle of density measurement involves weighing the material specimen in the fluid of known density and in air. The following mathematical expression represents the Archimedes principle.

$$\rho_{HMMCs} = \frac{m_a}{m_a - m_f}\rho_f,$$

where m_a is the mass of hybrid composite in air and m_f represents the mass of the same material in known density fluid, which is distilled water used for density measurement. The density of distilled water at 20°C is 0.998 g/cm^3. Using such parameter and approach, the actual density of base alloy and hybrid metal matrix composite is measured.

The porosity is a general aspect, which occurs during the fabrication process of composite/hybrid composites. Porosity measurement can be estimated by the following relation.

$$porosity\ \% = \frac{\rho_{th} - \rho_a}{\rho_{th}} * 100,$$

where ρ_{th} is the theoretical density and ρ_a is an actual density of MMCs/HMMCs. The estimation of theoretical density can be calculated by rule of mixture, which is shown by following relation for single-phase reinforced composite.

$$\rho_{th} = \rho_{th} V_m + \rho_r V_r,$$

where ρ_m and ρ_r are the density of matrix alloy and reinforced composite respectively. V_m and Vr are the volume fraction of matrix alloy and reinforcement, respectively.

The relation for the density estimation of single-phase reinforced can be modified for the hybrid composites, which incubates primary and secondary reinforcement. In this study, TiB_2 is selected as primary reinforcement and FA is selected as secondary reinforcement. The modified relations are shown below:

$$\rho_{th} = \rho_{al} V_{al} + \rho_{TiB_2} V_{TiB_2} + \rho_{FA} V_{FA},$$

where ρ_{al}, ρ_{TiB_2}, ρ_{FA} are the density of matrix aluminium alloy, Titanium Diboride and Fly ash, respectively; V_{al},$V_{TiB_2}$and V_{FA} are the volume fraction of matrix aluminium alloy, um Diboride and Fly ash, respectively. Also, the volume fraction of the matrix can be estimated by the following relation:

Hardness

Vickers hardness test is performed to evaluate the hardness value of the fabricated alloy and composite material. The test is performed according to ASTM E-92 standard. Indentation load are set to 20 kgf and held for 15 seconds. To obtain the average hardness, three different places were selected and tested on each test specimen and average of data reported as a result. The test was performed using Vickers hardness tester, installed at MSME Department, MANIT, Bhopal, M.P., India. The test is conducted at room temperature (28°C).

Tensile Test

The tensile test is performed according to ASTM E-8 standard. Specimen's fabrication is done from the casting as per the standard size and dimension, which is shown in figure 2. The test is carried out at room temperature on a computerised universal testing machine (Mech.CS.UTE,40T, Mechatronic Control System, India) installed on Material Testing Laboratory, MSME Department, MANIT, Bhopal, M.P., India. Three tests are performed for an average value of test results. The strain rate is kept at 2 mm/min to evaluate the result [28]. Ultimate tensile strength (UTS) collected and presented.

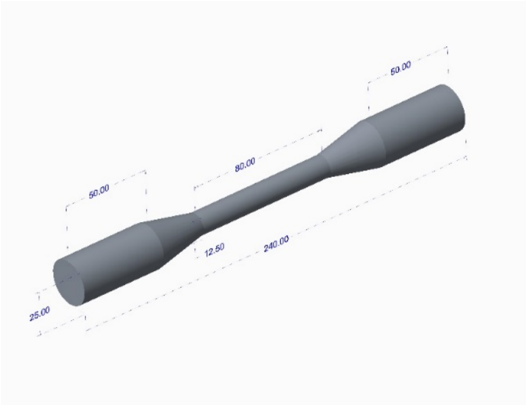

Figure 3: CAD Model of Tensile Test Specimen.

Compression Test

The compression test is performed according to ASTM-E9 standard. Specimen's fabrication is done from the casting, as per the standard size and dimension. The test is carried out at room temperature on a computerised universal testing machine (Mech.CS.UTE,40T, Mechatronic Control System, India) installed on Material Testing Laboratory, MSME Department, MANIT, Bhopal, M.P., India. Three tests are performed for an average value of test results. The strain rate is kept at 3 mm/min to evaluate the result. Ultimate compressive strength is collected at fracture point and presented.

Impact Test (Charpy)

Impact test by Charpy method is performed according to ASTM E-23 standard. Specimen's fabrication is done from the casting as per the standard size and dimension, which is shown in figure 4. The test is carried out at room temperature using Digital Impact tester of FINE make Model No FIT-300-D installed at Behaviour of Material Lab, Mech. Dept., MANIT, Bhopal, India.

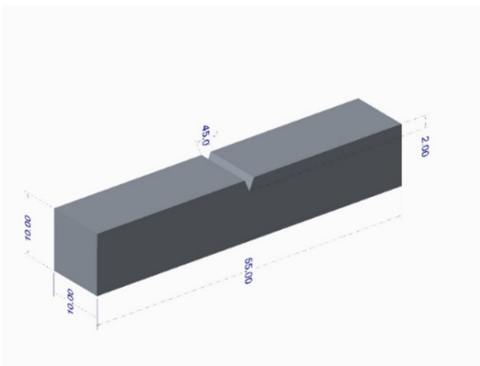

Figure 4: CAD Model of ASTM E-23 Standards Charpy Impact Test Specimen.

RESULTS AND DISCUSSIONS

Density

Deviation of actual and theoretical densities is shown in figure 5. The result shows variation in density with wt.% of reinforcement.

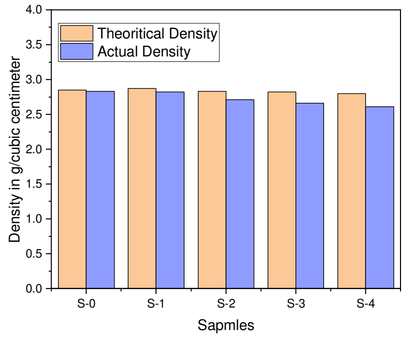

Figure 5: Deviation in the Actual and Theoretical Density of Hybrid Composite.

Hardness

The Vickers hardness test data of hybrid composite containing TiB_2 (1 wt.%) and Fly ash (2 wt.%, 3 wt.% and 4 wt. %) are represented by a bar graph, as shown in figure 6. The figure shows the relationship between hardness and wt.% of TiB_2 and FA particles. It is significantly observed that hardness of hybrid composite is higher than the matrix alloy. Such characterization is observed due to the hard nature of TiB_2 and FA particle. The maximum hardness value is achieved when reinforced with 1 wt.% TiB_2 and 2 wt.% FA, i.e., 140.52 VHN. The observed hardness value of alloy is 93.54 VHN, which is increased by 12.5% when 1 wt.% TiB_2 is reinforced in the matrix, i.e., 105.64 VHN. It is observed that hardness value further increases with secondary reinforcement along with primary reinforcement. The further increment in weight percentage of fly ash reduces the hardness of the hybrid composite. This variation in the pattern could be the reason for the non-uniform distribution of particle and porosity in the hybrid composite. The higher hardness value of composite material is due to high strain energy at the peripheral of the diffuse particles in the matrix [29]. This also signifies that the promising interfacial bonding occurs between the reinforced particle and the matrix alloy.

Figure 6: Test Specimen of VHN.

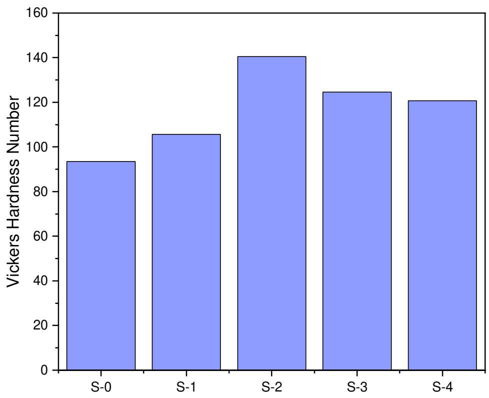

Figure 7: Effect of wt.% of Reinforcement on Hardness.

Tensile Test

The effect of TiB_2 and FA on the ultimate tensile strength is shown in figure 8. It is clearly shown in the bar graph that inclusion of the primary and secondary reinforcement increases the ultimate tensile strength respectively. Initially, tensile strength increases with primary reinforcement and furthermore increment is observed, while secondary reinforcement is included. The decrement trending tensile strength is observed when the weight percentage of secondary reinforcement increases. Maximum tensile strength 233.4 MPa is observed when 1 wt.% TiB_2 and 2 wt.% FA are reinforced. It is significantly observed that the ultimate tensile strength of the hybrid composite is higher than the matrix material. The addition of TiB_2 & FA reinforcement particles enhance the mechanical properties due to stress transference from matrix material to the reinforced particle, i.e., TiB_2 & FA; a similar trend is observed with TiB_2 and TiO_2 by Oñoro [30]. This phenomenon is an Orowan mechanism in which dislocation bypasses impenetrable obstacles, where a dislocation bows out considerably to leave a dislocation loop around a particle. Similarly, the prismatic loop leaves behind the particle by Hirsch mechanism [31, 32].

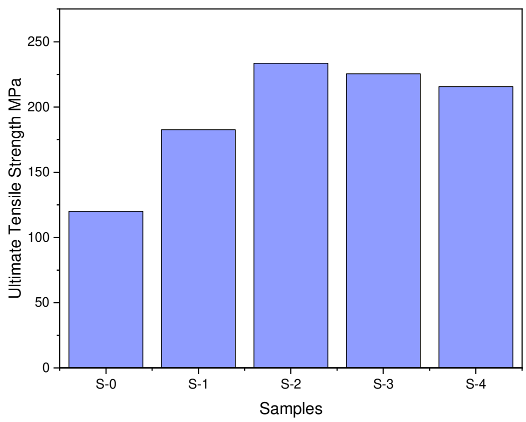

Figure 8: Effect of wt.% of Reinforcement on Ultimate Tensile Strength.

Compression Test

The compression test is performed in order to investigate the compressive strength of the alloy and hybrid composite. The test is performed on a computerized universal testing machine in accordance with ASTM-E9 at room temperature. The compressive strength is considered at the fracture of the sample. The result obtained from the test is presented in figure 10. The result shows that the inclusion of the reinforced particle in the alloy matrix increases the compressive strength, but

after a certain limit of the reinforcement, the compressive strength decreases. The compressive strength of the alloy is 613.52 MPa, it increases to 615.35 MPa in AA7068- 1 wt.% TiB_2 and 655.54 MPa in AA7068- 1 wt.% TiB_2 and 2 wt.% FA, which is the highest strength obtained. This pattern is observed due to the addition of a hard ceramic phase in the matrix alloy and good interfacial bonding between matrix and reinforcement. Further increment in secondary reinforcement reduces the compressive strength of the hybrid composite. This trend is observed due to the increment in brittleness and porosity in the material.

Figure 9: Test Specimen of Compression Test.

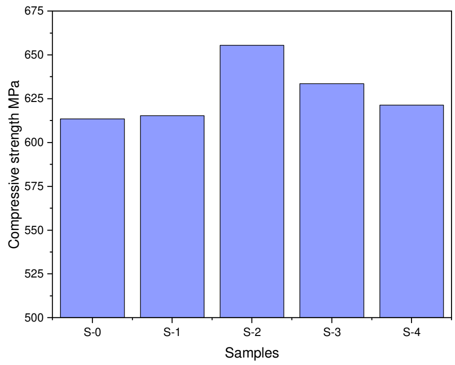

Figure 10: Effect of wt.% of Reinforcement on Impact Strength.

Charpy Impact Test

To investigate the energy absorption capacity of aluminium alloy and hybrid composite, a Charpy impact test is performed according to ASTM- E23 standard. The test is performed at room temperature on the digital impact testing machine Model/FIT/300D of FINE make. It is observed from the result that, as shown in figure 11, the impact strength of the material significantly decreases with the weight percentage of reinforcement. The result data shows that AA7068 possess the highest impact strength, i.e., 4.35 joules. Furthermore, 3.6, 2.9, 1.45 and 1.01 joules impact strength are possessed by AA7068- 1 wt.% TiB_2- 0 wt.% FA, AA7068- 1 wt.% TiB_2- 2 wt.% FA, AA7068- 1 wt.% TiB_2- 3 wt.% FA and AA7068- 1 wt.% TiB_2- 4 wt.% FA composites, respectively.

It is inferred with the collected data that the dispersion of hard ceramic particle in the ductile matrix causes adverse effect on the energy absorption capacity of the material. It signifies that less impact resistance is offered by hybrid composite with an increasing weight percentage of reinforcement. This behavior occurs due to rigid particle, which increases the brittleness of the material. The high magnitude of load with velocity break out the interface of particle and

alloy, such de-cohesion phenomenon develops new surfaces after releasing the energy. On the contrary, alloy absorbs the impact energy and deforms plastically without fracture.

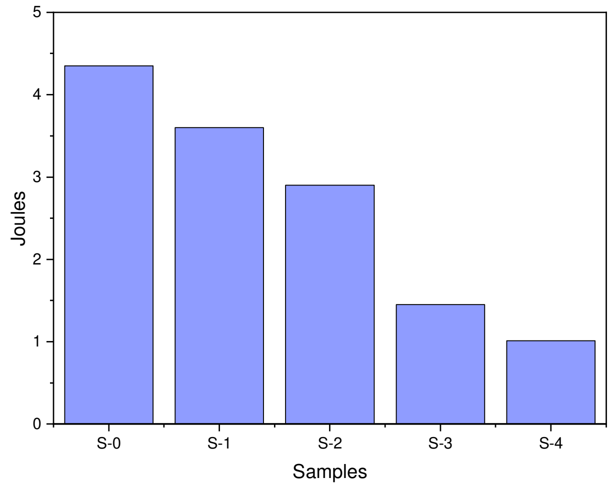

Figure 11: Effect of wt.% of Reinforcement on Impact Strength.

CONCLUSIONS

In the present experimental investigation AA7068-TiB_2-FA hybrid composite has been synthesized through stir casting route followed by the mechanical characterization. On the basis of experimental data and analysis, the following the conclusions have been made:

- The inclusion of the hard ceramic particle of TiB_2 and FA in AA7608 increases the specific gravity of the material.
- The hardness of the material is increased due to the dispersion of TiB_2 and FA in AA7608 matrix. The hardness of hybrid composite (1 wt.% TiB_2- 2 wt.% FA) is increased by 50% with respect to the base alloy.
- The ultimate tensile strength of hybrid composite (1 wt.% TiB_2- 2 wt.% FA) is increased by 94%, with respect to the base alloy.
- The highest compressive strength is observed with the combination of 1 wt.% TiB_2- 2 wt.% FA in matrix alloy, i.e., 655 MPa.
- The highest impact strength is observed in AA7068, which continuously decreases with the inclusion of reinforcement.

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